LightMAT
Lightweight Materials
CONSORTIUM

Mitigating Corrosion in Mg Sheet in Conjunction with a Sheet-Joining Method that Satisfies Structural Requirements within Subassemblies

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U.S. DEPARTMENT OF ENERGY | National Laboratory Impact Initiative

EMN Energy Materials Network

Project ID # mat143

April 23, 2018

Overview

Timeline

- Start: Oct. 2017
- Finish: Sept. 2019
- % complete (time): ~25%
- % spent (budget): ~30%

Budget

- Total project funding
  - DOE: $ 300K
  - Industrial cost share: $ 425K
- Funding Since Inception: $ 300K
- Future Funds Anticipated: $ 0

Technology Gaps/Barriers

- Lack of corrosion resistant Mg alloys
- Lack of cost-effective, durable protective coatings
- Limited availability of joining technologies and corrosion protection systems for Mg-X mixed material joints

Partners

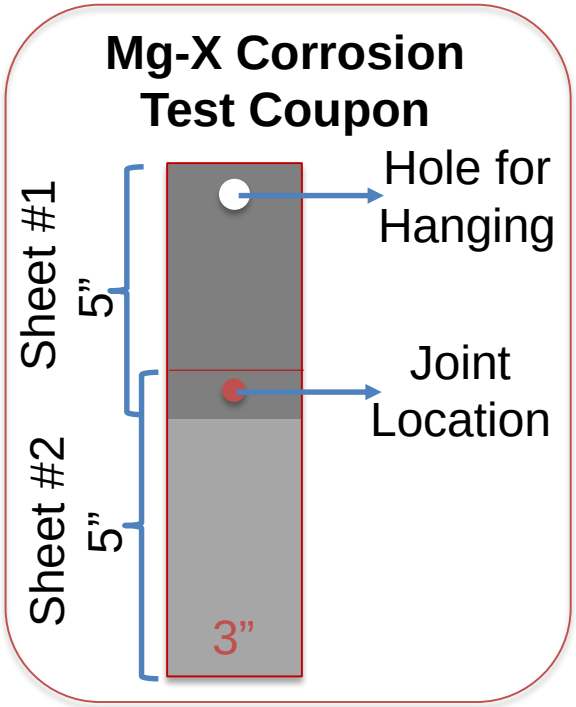
- Tier-1 Supplier: Magna International - Stronach Centre for Innovation (SCFI)

Relevance/Objective

- Despite a weight saving potential of 60-75% for Mg alloys relative to steel, galvanic corrosion and the cost of corrosion protection are key barriers in the greater use of Mg alloys in automotive components
- Cost-effective joining and assembly of Mg sheet panels, while maintaining Class-A surface finish, is challenging
- This project will evaluate the corrosion behavior of commercially coated Mg-alloy sheets, and of Mg-X similar/dissimilar joints made by three candidate joining techniques
- Use of LightMAT's resources (at PNNL) will help industry expedite technology development by enabling access to advanced testing and characterization techniques and scientific expertise, all under one roof

Approach

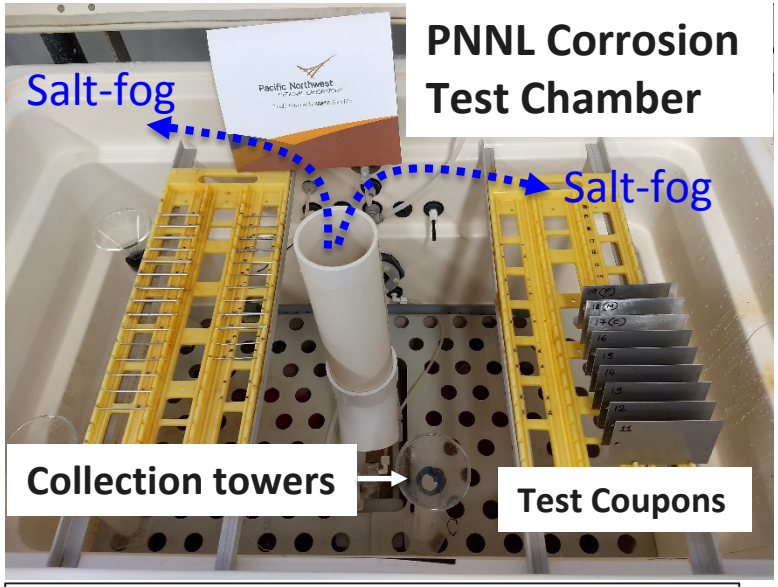
- Test materials: AZ31 Mg sheet
  - Bare sheets
  - Henkel pre-treated
  - Henkel pre-treated + E-coated
  - Similar and dissimilar joints
- Joining technologies
  - Arplas resistance spot welding
  - Clinch lock
  - Breakaway stem rivet
- Year 1
  - Baseline sheet → ~30 samples
  - Similar joints (Mg/Mg) → ~70 samples
- Year 2
  - Dissimilar joints (Mg/Al, Mg/steel) → ~100 samples
- ASTM B117 (salt spray) test
  - Weight change
  - Microstructural analysis (e.g. Optical and electron microscopy, EDS, XPS, XRD, etc.)
  - Mechanical testing (quasi-static tension, nanoindentation)



Task/Milestone Summary

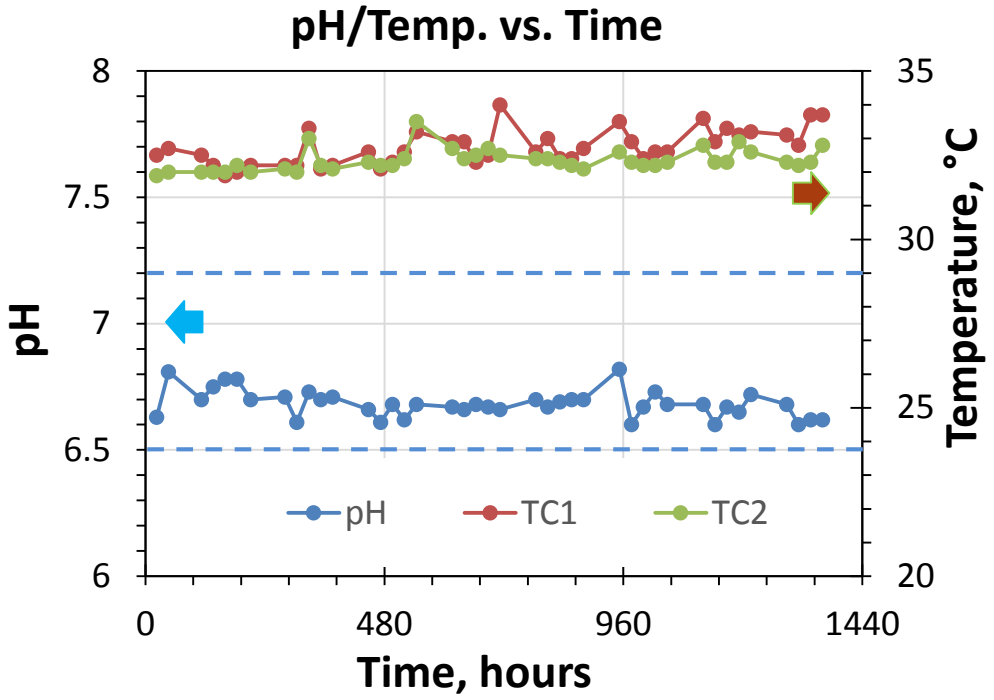
Year No.	Task/ Sub-task No.	Task Name	Duration (Months) (Start)	(Finish)	Responsible Party	Current Status
I	M1	Determine Comprehensive Test Matrix and Design of Experiment	1	2	Magna	Complete
	M2	Sample Preparation	2	6	Magna	On-going
	P1	Baseline Characterization	1	9	PNNL	
	1.1	Corrosion Testing	1	9	PNNL	
	1.2	Microstructural Characterization	1	9	PNNL	
	1.3	Mechanical Property Characterization	1	9	PNNL	To be started/ on- track
	M3	Sample Joint Assy. – Similar Alloys	6	12	Magna	
	Milestone 1	Determine Load to Failure @ Interface		9	PNNL	
I-II	P2	Similar Joints Characterization	7	18	PNNL	
	2.1	Corrosion Testing	7	18	PNNL	
	2.2	Microstructural Characterization	7	18	PNNL	
	2.3	Mechanical Property Characterization	7	18	PNNL	
	M4	Sample Joint Assy. – Dissimilar Alloys	8	16	Magna	
II	Milestone 2	Identify Chemical Species Transport		20	PNNL	
	P3	Dissimilar Joints Characterization	13	24	PNNL	
	3.1	Corrosion Testing	13	24	PNNL	
	3.2	Microstructural Characterization	13	24	PNNL	
	3.3	Mechanical Property Characterization	13	24	PNNL	
	M5	Formulate Report	23	24	Magna	

Accomplishments
Experimental Setup (ASTM B117)



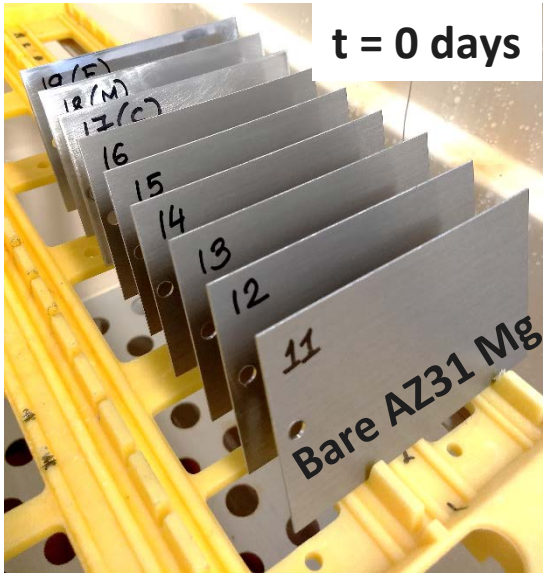
ASTM B117 Test Conditions

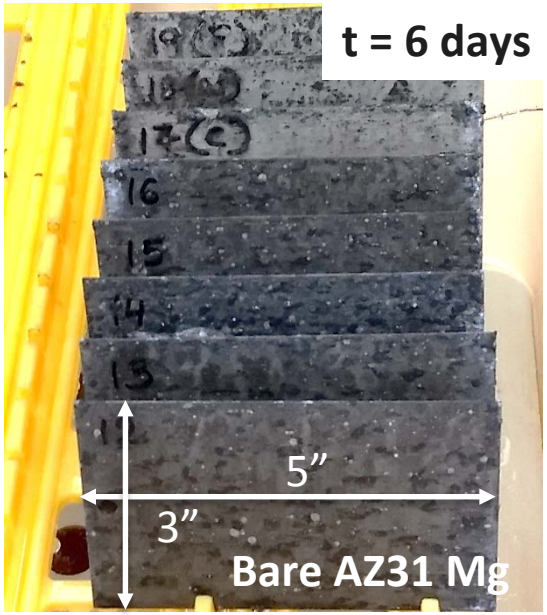
Test chamber temperature: 35±2° C
5% NaCl solution
pH of the solution: 6.5 – 7.2
Fog collection rate: 1 – 2 ml/ hr
Test duration: Up to 1500 hrs. (62 days)

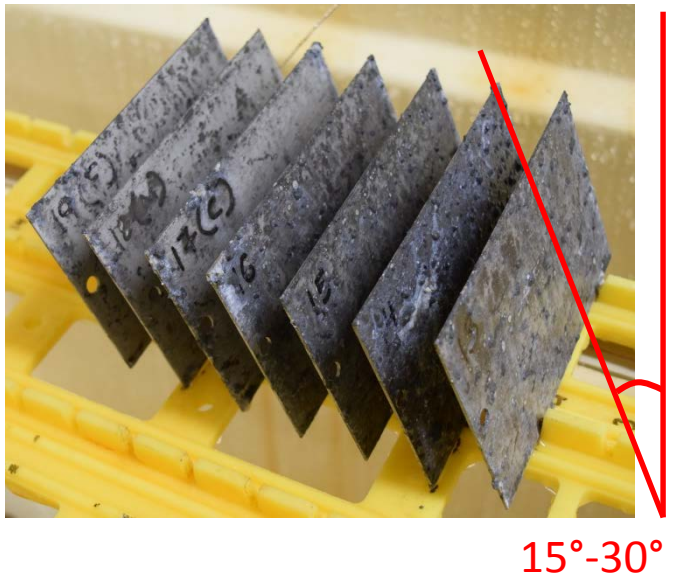


- Test conditions are maintained within the limits specified by the ASTM standard for ~60 days

Accomplishments
Influence of Sample Positioning on Corrosion



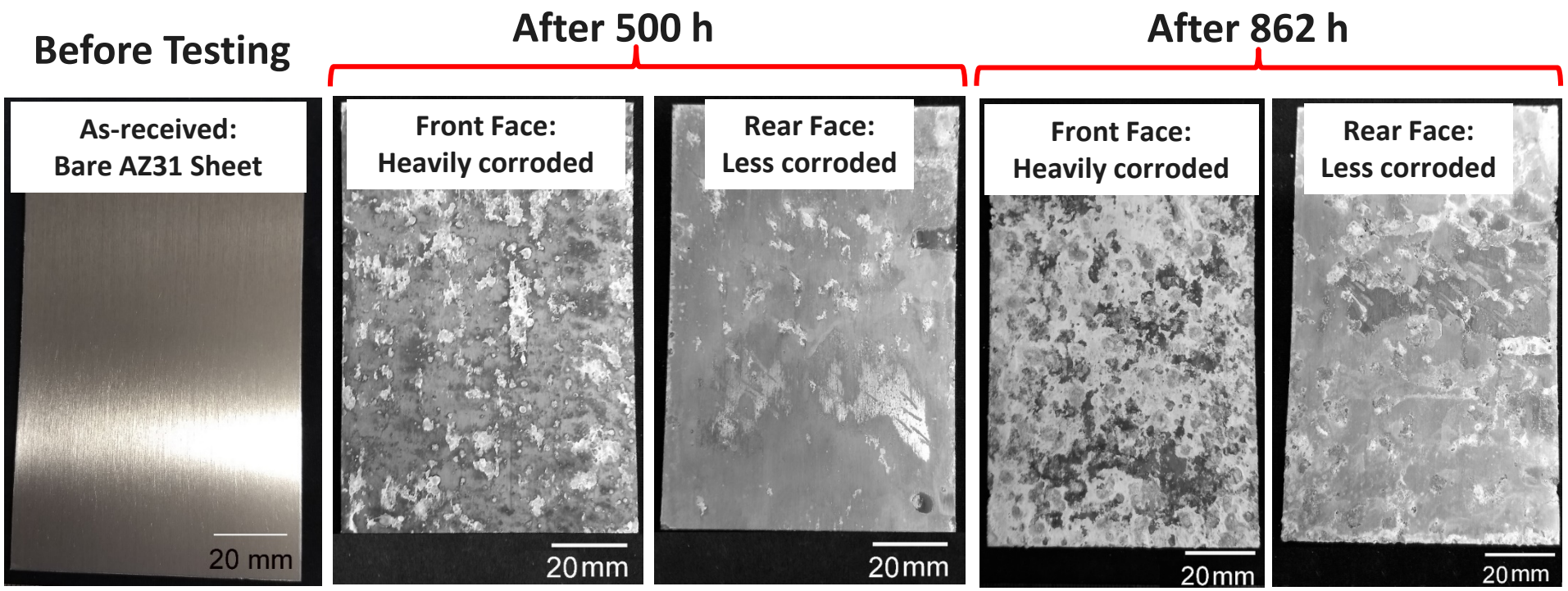




- Bare AZ31 Mg testing complete
- Significant general and pitting corrosion observed after six days of continuous test

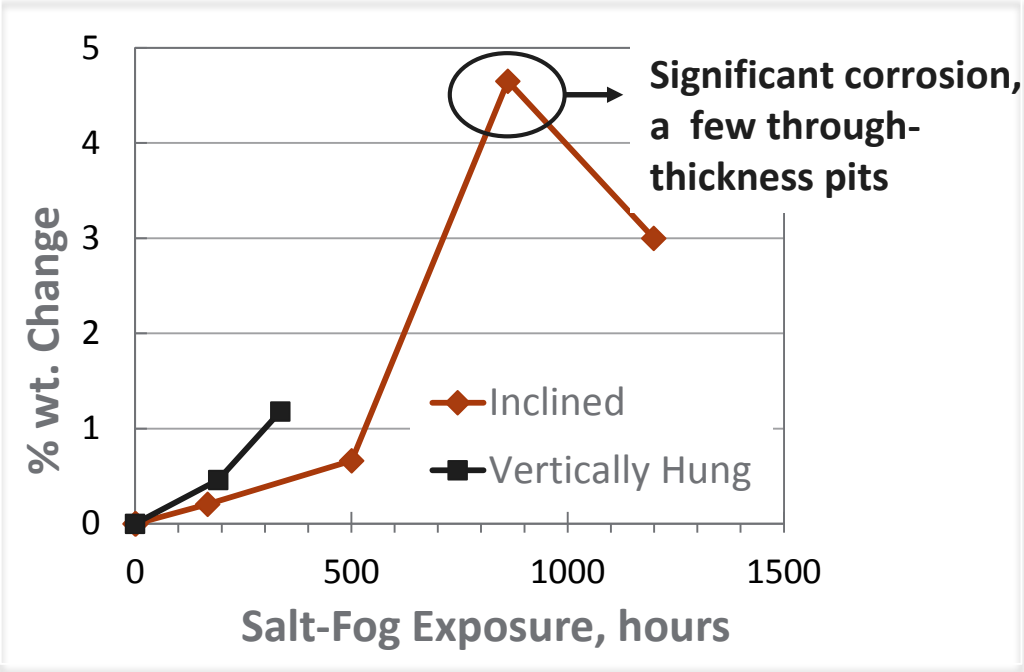
- Inclined samples show dissimilar corrosion extent on the front and back face

Accomplishments
Influence of Sample Positioning on Corrosion



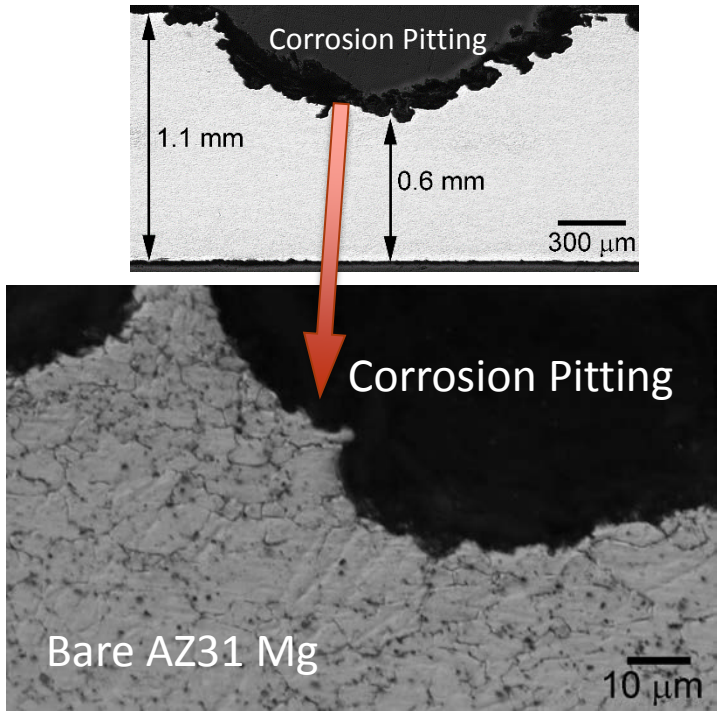
- Inclined samples show dissimilar extent of corrosion on the front vs. back face

Accomplishments
Weight Change During Corrosion



- Weight increase → Corrosion product (mainly $Mg(OH)_2$) deposition
- Vertically hung samples → Faster but uniform corrosion rate

Bare AZ31 Mg, 240 h



- Main modes of corrosion seem to be uniform corrosion and pitting corrosion

Responses to Previous Years Reviewers' Comments

- This is the 1ST year of this project for AMR review, therefore there are no reviewer comments from prior years

Collaboration and Coordination

Magna-Stronach Centre for Innovation

- CRADA between PNNL and Magna-SCFI
- Magna-SCFI supplies all the Mg sheets and corrosion test requirements

Henkel

- Magna-SCFI's partner providing pre-treatment and e-coatings on Mg AZ31

Various Tier-1 Suppliers

- Fabricating various joint samples

Remaining Challenges and Barriers

- Effect of joining technique on pre-treated and coated surface is unknown
- Influence of pre-treatments and coatings on joint corrosion behavior is unknown

Proposed Future Work

- Evaluation of coated samples for baseline characterization (Year I)
- Evaluation of similar joints (Mg/Mg) (Year I)
  - Corrosion testing
  - Microstructural characterization and identification of potential sites that are prone to corrosion
- Effect of microstructure on corrosion performance (Year I-II)
  - Effect of grain size, i.e. fine grain vs. coarse grain
  - Effect of precipitates: Discontinuous vs. continuous
- Evaluation of dissimilar joints (Mg-Al and Mg-steel) (Year II)
  - Corrosion testing
  - Microstructural characterization

Any proposed future work is subject to change based on funding levels

Summary

- AZ31 Mg (bare sheets) has been tested for 1500 hours according to ASTM B117 standard
  - Main corrosion mode appears to be uniform corrosion and pitting
  - Sheet through-thickness pits were observed within 800 hours of testing
- Sample positioning within the corrosion chamber can be important, specially for asymmetric joint configurations
  - Vertically hung samples appear to corrode uniformly on both faces while inclined positioned sample show greater corrosion on the front face
- Sample weight increases with corrosion exposure due to the formation of corrosion product which was identified as $Mg(OH)_2$ by XRD characterization

Technical Backup Slides

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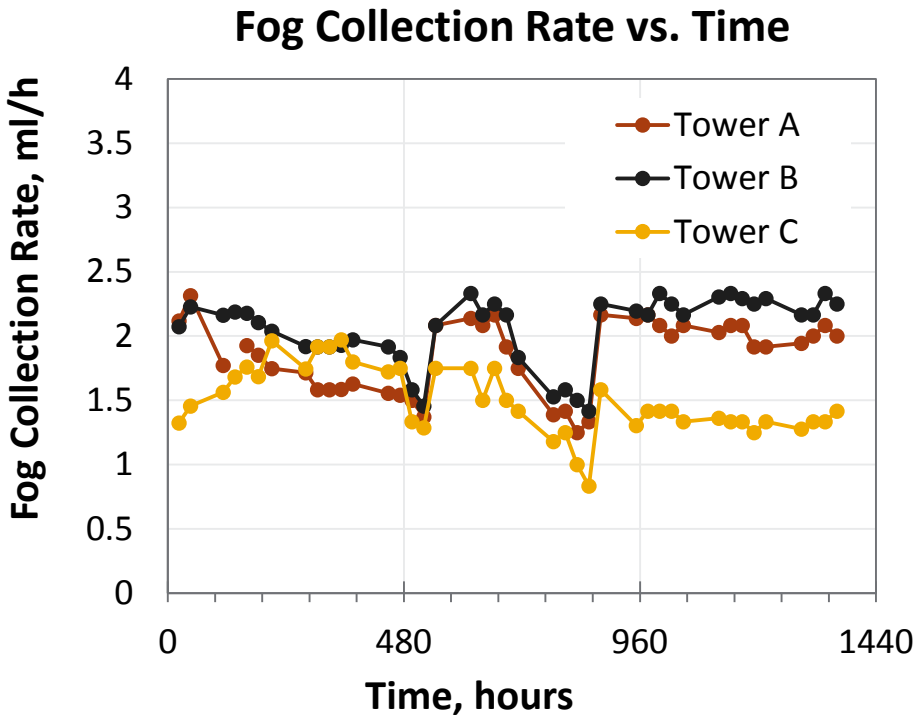
DOE ANNUAL MERIT REVIEW, WASHINGTON, D.C., JUNE 2018

Project ID # mat143

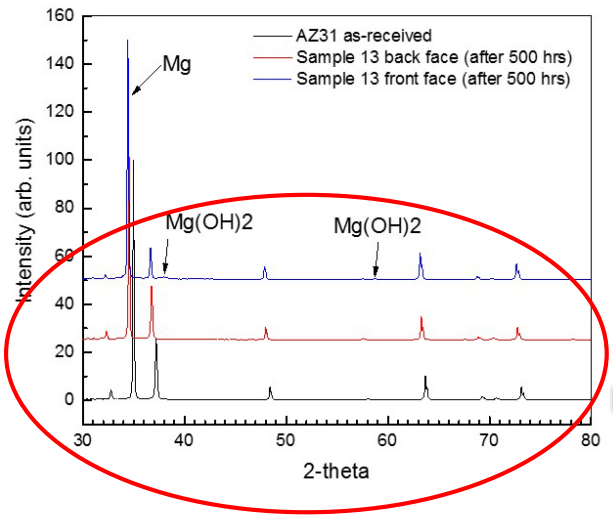
Backup Slide
ASTM B117 Test Monitoring

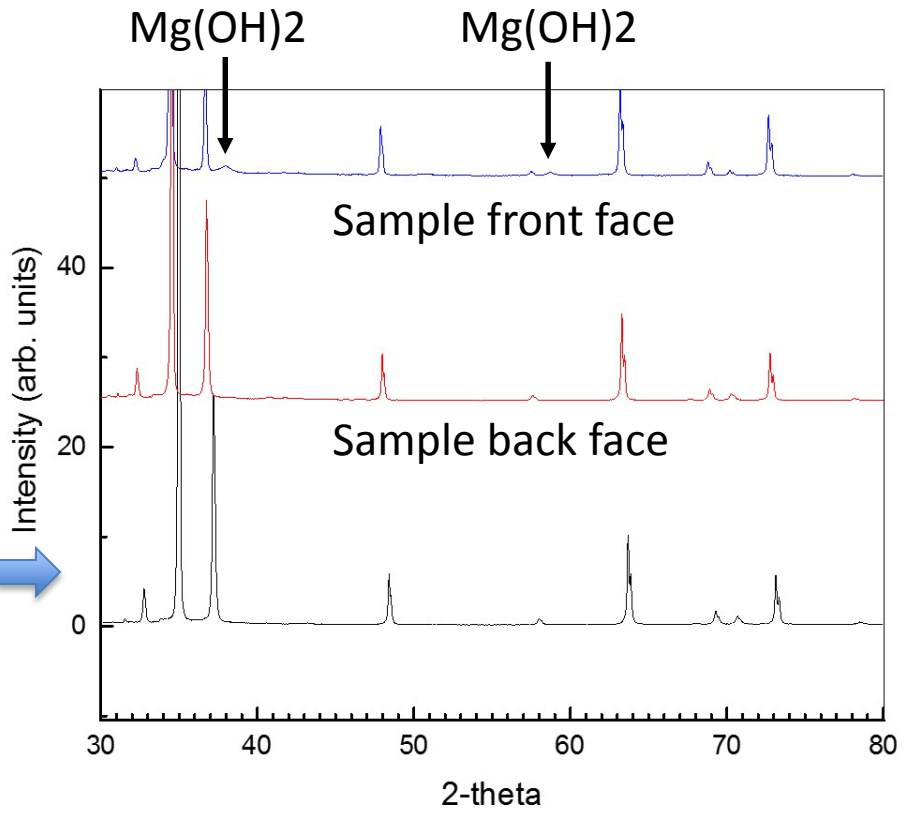


- Fog collection rate maintained at ~1-2 ml/hr

Backup Slide
X-ray Diffraction of Corrosion Products

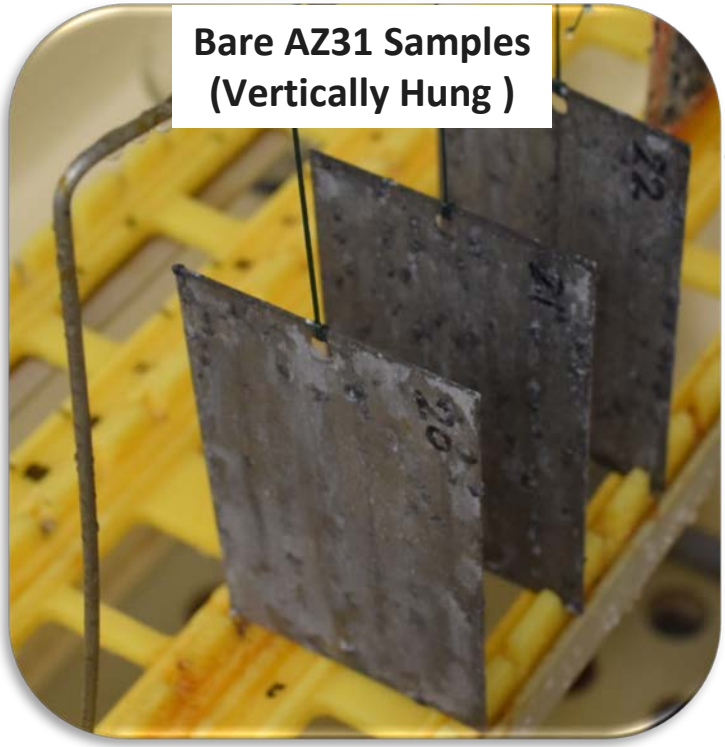
Inclined Resting Samples



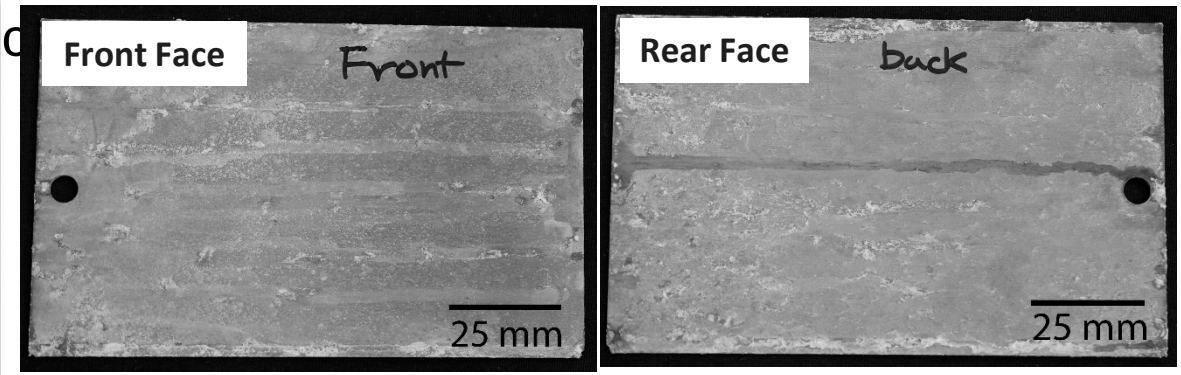


- XRD analysis confirmed the presence of $Mg(OH)_2$ as the corrosion product, on the front face
- $Mg(OH)_2$ could not be detected on the back face due to reduced extent of corrosion
- Greater corrosion attack on the front face is attributed to sample inclination

Backup Slide
Influence of Sample Positioning on Corrosion



After 192 h (8 days)



- Vertically hung samples show similar extent of corrosion on the front vs. back face